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Description

The present invention relates to an electron emission device, and more particularly to such device having an electron emission electrode with at least one pointed end and a counter electrode positioned opposite to said pointed end.

As an electron source there has been utilized thermal electron emission from a thermal cathode. Such an electron emission utilizing a thermal cathode has been associated with drawbacks of a large energy loss in heating, the necessity of heating means, a considerable time required for preparatory heating, and a tendency of instability of the system caused by heat.

For these reasons there have been developed electron emission devices not relying on heating, among which there is known an electron emission device of the field effect (FE) type.

Fig. 1 is a schematic view of a conventional electron emission device of the field effect type.

As shown in Fig. 1, the conventional electron emission device of the field effect type is composed of a cathode chip 20 formed on a substrate 23 and having a sharply pointed end for obtaining a strong electric field, and an attracting electrode 22 formed on the substrate 23 across an insulating layer 21 and having an approximately circular aperture around the pointed end of the cathode chip 20, wherein a voltage is applied across said cathode chip 20 and said attracting electrode 22 with its positive value at the latter, thereby causing the electron emission from the pointed end of the cathode chip 20 where the intensity of the electric field is larger.

In document US-A-3 812 559 a multitude of electrodes in shape of cones is formed on a substrat thereby constituting an embodiment of an emission electrode. A second electrode consists of a film of the same conductor with an insulating layer between said two electrodes, wherein holes in the second electrode and the insulating layer let the emitted electrons emerge with energies corresponding to a voltage applied between said two electrodes.

From document EP-A-0 260 075, which describes prior art under Article 54(3) EPC, it is known to form an electron emission device comprising an electron emission electrode with at least one pointed end and a counter electrode positioned opposite to said pointed end, both formed by fine working of a substantially coplanar conductor layer laminated on an insulating substrate.

However, in such conventional field effect electron emission device, the sharp pointed end is difficult to make, and has been generally manufactured by electrolytic polishing followed by remolding. This process is however cumbersome, requires many working steps, and is difficult to automate as it involves various empirical factors. Consequently the manufacturing conditions fluctuate easily, and the product quality cannot be made constant. Also the laminate structure tends to result in a registration error between the cathode chip 20 and the attracting electrode 22.

In consideration of the foregoing, the object of the present invention is to provide an electron emission device being formed as a thin structure wherein the manufacturing process of an electron emission electrode with at least one pointed end is simplified.

According to the invention this object can be accomplished by an electron emission device comprising an electron emission electrode with at least one pointed end and a counter electrode positioned opposite to said pointed end, both formed by fine working of a substantially coplanar conductor layer laminated on an insulating substrate, wherein at least said pointed end is composed of a material of high melting point and low work function.

The intensity of an electric field generally required for an electron emission is 10^8 V/cm or higher, and, in the presence of such an electric field, the electrons in the solid substance pass through a potential barrier at the surface by a tunnel effect, thus causing the electron emission.

When a voltage E is applied between the electron emission electrode and the counter electrode, and the radius r of curvature of an electron emitting portion of the electron emission electrode is small, the intensity of electric field E at said electron emitting portion satisfies a relation:

$$E \propto \frac{V}{r}$$

In the electron emission, the range of the energy of the emitted electrons should preferably be small in order to improve the convergence of the electrons, and the device is preferably drivable with a low voltage. For these reasons said radius r of curvature should preferably be as small as possible.

Also in order to stabilize the electron emission voltage, it is desirable to precisely control the distance between the electron emission electrode and the counter electrode.

The present embodiment is to minimize the radius of curvature of the electron emission electrode and to precisely control the distance between said electron emission electrode and the counter electrode,

utilizing fine working technology.

In another embodiment of the present invention, the above-mentioned object can be achieved by an electron emission device provided with an electron emission electrode having a pointed end on an insulating substrate in such a manner as to be substantially coplanar to said substrate, and an attracting electrode positioned opposite to said pointed end and having an electron emission aperture.

In the present embodiment, an electron emission electrode having a pointed end and an attracting electrode positioned opposite to said pointed end and having an electron emission aperture are formed substantially coplanar to the surface of an insulating substrate, and a voltage is applied across said electron emission electrode and said attracting electrode, with the positive side at the latter, to cause electron emission from said pointed end through said electron emission aperture substantially coplanar to the surface of said insulating substrate.

Fig. 1 is a schematic view of a conventional field effect electron emission device;

Fig. 2 is a schematic view of a first embodiment of an electron emission device according to the present invention;

Figs. 3(A) to 3(D) are schematic views showing a process for forming a recess on a substrate;

Fig. 4 is a schematic view of an example of an FIB apparatus;

Fig. 5 is a schematic cross-sectional view of a second embodiment of the electron emission device of the present invention;

Fig. 6 is a schematic view of a third embodiment of the electron emission device of the present invention;

Fig. 7 is a schematic view of a fourth embodiment of the electron emission device of the present invention;

Fig. 8 is a schematic view of a fifth embodiment of the electron emission device of the present invention;

Figs. 9(A) to 9(D) are schematic views showing the process for forming a recess on a substrate;

Fig. 10 is a schematic view of a sixth embodiment of the electron emission device of the present invention; and

Fig. 11 is a schematic view of a seventh embodiment of the electron emission device of the present invention.

Now the present invention will be clarified in detail by embodiments thereof shown in the attached drawings.

Fig. 2 is a schematic view of a first embodiment of an electron emission device according to the present invention.

As shown in Fig. 2, a conductive layer of a thickness of ca. 500 Å is deposited for example by vacuum evaporation on an insulating substrate 1 such as glass, and an electron emission electrode 2 and a counter electrode 3 are formed by maskless etching technology such as FIB to be explained later.

A pointed end of the electron emission electrode 2 is formed as a triangular or parabolic shape to minimize the radius of curvature, and finished as a wedge-shaped or parabolic-shaped pillar.

The electron emission electrode 2 is preferably formed with a material of a high melting point, since it is formed to minimize the radius of curvature as explained above and generates a large amount of heat because of a high current density, and is also preferably formed with a material of a low work function in order to reduce the applied voltage. Examples of such material include metals such as W, Zr or Ti, metal carbides such as TiC, ZrC or HfC, metal borides such as LaB_4, SmB_4 or GdB_4, and metal silicides such as WSi_2, $TiSi_2$, $ZrSi_2$ or $GdSi_2$.

The counter electrode 3 is not limited in form, but, if formed linearly opposite to the pointed end of the electron emission electrode as in the present embodiment, it can be manufactured easily and can cause efficient electron emission from the electron emission electrode 2.

In the electron emission device of the above-explained structure, a voltage is applied, by means of a power source 4, across the electron emission electrode 2 and the counter electrode 3, with its positive value applied to the latter. Thus a strong electric field is applied to the pointed end of the electron emission electrode 2 to induce electron emission. The emission current density J in such state is given by the equation of Fauler-Nordheim as follows:

$$J_E = 1.54 \times 10^{-6}\frac{E^2}{\phi}\exp(-6.83 \times 10^7\frac{\phi^{3/2}}{E})\ A/cm^2$$

wherein E is the electric field and ø is work function.

For example, if the pointed end of the electron emission electrode 2 is formed as a parabolic formed blade with a head angle of 30° and distanced from the counter electrode 3 by 0.1μ m with a voltage of 80V therebetween, there is obtained an electric field of 2.0×10^7 V/cm, with an emission current of 3.7×10^{-2} A/cm^2 for a work function of metal of 3.5.

The electrons emitted from the pointed end of the electron emission electrode 2 are partly absorbed by the counter electrode 3, but those with lower energy are diffracted, by low energy electron beam diffraction, by the crystal lattice of the counter electrode 3 and are emitted in a direction perpendicular to the insulating substrate 1. Such electrons having a component of motion in the direction perpendicular to the insulating substrate 1 can be utilized as the electron source.

In order to increase the intensity of the electric field between the electron emission electrode 2 and the counter electrode 3 and to efficiently obtain the electrons without electron charging on the insulating substrate, it is desirable to form a deep recess on the substrate where the electric field is concentrated, for example by dry etching. The manufacturing process of such recess will be explained in the following.

Figs. 3(A) - 3(D) are schematic views showing the process for forming a recess on the substrate.

At first, as shown in Fig. 3(A), a SiO_2 layer 6 is formed on a silicon substrate 5 for example by thermal oxidation.

Then as shown in Fig. 3(B), there is formed a conductive layer 7 composed for example of tungsten (W).

Then as shown in Fig. 3(C), there are formed an electron emission electrode 2 having a pointed end and a linear counter electrode 3 by means of fine working technology such as FIB.

Finally, as shown in Fig. 3(D), the SiO_2 layer 6 is selectively etched such as wet etching utilizing fluoric-nitric etching liquid or plasma etching utilizing reaction gas such as CF_4. The etching is conducted through the gas between the electron emission electrode 2 and the counter electrode 3 and proceeds isotropically to form a recess 8, whereby the SiO_2 layer 6 in a part of the concentrated electric field contributing to the electron emission is completely removed.

In the following there will be explained the fine working technology to be employed in the present embodiment.

Fine working is ordinarily conducted by a photolithographic technology involving a photoresist process and an etching process, but a precision below 0.7 μm is difficult to achieve due to mask aberration etc.

The fine working technology to be employed in the present embodiment should be capable of fine working below 0.7 μm for enabling the use of low voltage, and can be FIB mentioned above.

Fig. 4 shows an example of a FIB apparatus. The FIB technology utilizes scanning with a metal ion beam concentrated to submicron size to achieve fine working of submicron order, utilizing the sputtering phenomenon on a solid surface.

In Fig. 4, atoms of a liquid metal are emitted from an ion source 9 with an attracting electrode, and a desired ion beam is selected by an EXB mass selector 11 (in case of liquid alloy). Then the ion beam accelerated for example of 80 keV is concentrated by an objective lens 12 to a size of about 0.1μ m, and scans a substrate 14 by means of deflecting electrodes 13. The registration of the ion beam is achieved by a specimen stage 15.

Fig. 5 is a schematic cross-sectional view of a second embodiment of the electron emission device of the present invention.

The electron emission device of the present embodiment has an electron source of the same structure as in the foregoing embodiment, and, for effectively extracting electrons having different vectors of motion, an attracting electrode 16 which is positioned above the electron source. When a power source 17 applies a voltage across the electron emission electrode 2 and the attracting electrode 16 with the positive side at the latter, the electrons emitted from the electron emission electrode 2 can be efficiently obtained in a direction perpendicular to the insulating substrate 1.

Fig. 6 is a schematic view of a third embodiment of the electron emission device of the present invention.

The electron emission electrode 2 is provided with plural pointed ends with a precisely controlled distance to the counter electrode 3, by means of a fine working technology such as FIB, so that the voltages applied for the electron emission show only a limited fluctuation and the quantities of the electrons emitted from different pointed ends become approximately equal.

Fig. 7 is a schematic view of a fourth embodiment of the electron emission device of the present invention.

In the electron emission device of the present embodiment, plural electron emitting units A are formed by wirings 18_1 - 18_5 each having plural pointed ends, and by wirings 19_1 - 19_5 positioned as a matrix

arrangement with respect to said wirings 18_1 - 18_5 and having counter electrodes respectively corresponding to the pointed ends. The wirings 18_1 - 18_5 are given a potential of 0 V in succession, and a predetermined voltage V is given to transistors Tr1 - Tr5 respectively connected to the wirings 19_1 - 19_5 in synchronization with successive selection of the wirings 18_1 - 18_5 to emit electrons from desired electron emitting units.

As explained in the foregoing, the first to fourth embodiments allow to minimize the radius of carvature of the electron emission electrode and to precisely control the distance thereof from the counter electrode by means of a fine working technology, thereby providing the following advantages of:

(1) low voltage drive with reduced fluctuation in the energy of emitted electrons;

(2) a simplified manufacturing process, since a fine working technology such as FIB allows to form the electron emission electrode and the counter electrode with a high precision, without additional steps for example of remolding; and

(3) a thinner, smaller and lighter structure since the electron emission electrode and the counter electrode can be precisely formed in a planar structure.

Fig. 8 is a schematic view of a fifth embodiment of the electron emission device of the present invention.

A conductive layer of a thickness of 500 - 1000 Å is formed by vacuum evaporation on an insulating substrate 1 such as glass, and there are formed, by a maskless etching technology such as FIB explained above, an electron emission electrode 2 and lens constituting members 3A - 3D constituting a so-called Butler bipotential lens. The lens constituting members 3A, 3B are also used as attracting electrodes, to which a higher potential with respect to the electron emission electrode 2 is given by means of a power source 4A whereby electrons are emitted from said electrode 2 toward a space between the lens constituting members 3A, 3B.

Said electrons attracted to the space between the lens constituting members 3A, 3B can be converged to a desired focus point, by suitably selecting the ratio of the voltage V_1 to V_2 wherein V_1 is supplied to the lens constituting members 3A, 3B and V_2 is supplied to the lens constituting members 3C, 3D by means of a power source 4B and by suitably selecting the distances between the electron emission electrode 2 and the lens constituting members 3A - 3D.

The form and material of the electron emission electrode 2 in the present embodiment can be the same as in the first embodiment.

The lens electrodes are not limited to those of bipotential type explained above but can be of any type having electron converging effect.

In order to increase the intensity of the electric field between the electron emission electrode 2 and the lens constituting members 3A, 3B and to efficiently extract the electrons through a gap between the lens constituting members 3C, 3D without electron charging on the insulating substrate, it is desirable to form a recess on the insulating substrate by means for example of dry etching, corresponding at least to the passing area of electrons emitted from the pointed end of the electron emission electrode and/or the area of electric field applied to said electrons. In the present embodiment, as shown in Fig. 8, a recess is formed on the insulating substrate 1, except the areas of the electron emission electrode 2 and the lens constituting members 3A - 3D.

Figs. 9(A) - 9(D) are schematic views showing the process of forming said recess on the substrate.

At first, as shown in Fig. 9(A), a SiO_2 layer 6 is formed on a silicon substrate 5 for example by thermal oxidation.

Then, as shown in Fig. 9(B), a conductive layer 7 composed for example of tungsten is formed.

Then, as shown in Fig. 9(C), a fine working process such as FIB is conducted to form the electron emission electrode 2 and the lens constituting members 3A - 3D (of which members 3B, 3D are not shown).

Finally, as shown in Fig. 9(D), the SiO_2 layer 6 is selectively etched for example by wet etching utilizing fluoric-nitric etching liquid or by plasma etching utilizing a reactive gas such as CF_4. The etching is conducted isotropically on the insulating substrate 1 except those portions thereof which are in contact with the electron emission electrode 2 and the lens constituting members 3A - 3D, whereby the surface of the insulating substrate corresponding to the area of electric field is completely removed. The recess 8 is formed in this manner. The structure of the present embodiment can also be formed by the fine working technology utilizing the FIB apparatus shown in Fig. 4.

Fig. 10 is a schematic view of a sixth embodiment of the electron emission device of the present invention.

The electron emission device of the present embodiment is provided, in addition to the structure of the device of the above-explained fifth embodiment, with linear electrostatic deflecting plates 30, 31 and einzel-lens members 32 - 37 on the insulating substrate 1.

Same components as those in said fifth embodiment are represented by same numbers and will not be explained further.

By means of the electron emission device of the present embodiment, being capable of linear deflection and focusing on the insulating substrate 1, it is possible to achieve highly precise deflection and focusing, and to form the entire device lighter and thinner.

It is also possible to deflect the electrons two-dimensionally, by forming a device for deflecting in another direction outside the insulating substrate 1.

Plural units of the above-explained electron emission device can be employed to constitute an electron beam image writing apparatus.

Fig. 11 is a schematic view of a seventh embodiment of the electron emission device of the present invention.

The electron emission device of the present embodiment is provided with plural pointed ends of the type shown in Fig. 5, and corresponding to each pointed end there are provided lens constituting members 3A', 3C' constituting a bipotential lens.

In the present embodiment the plural pointed ends and the lens constituting members 3A', 3C' can be formed precisely with a fine working technology such as FIB, so that the voltages for electron emission show only small fluctuation and the quantities of electrons emitted from the different pointed ends become substantially equal.

As explained in the foregoing, the fifth to seventh embodiments have the electron emission electrode and the attracting electrode on the same insulating substrate and it is possible to extract the electrons in a direction substantially parallel to the surface of said substrate, thereby providing following advantages:

(1) The electron emission electrode and the attracting electrode can be prepared in the same step, with reduced costs and with an improved relative positional precision; and

(2) The device can be made thinner, smaller and lighter as the electron emission electrode and the attracting electrode can be formed on the same insulating substrate.

Claims

1. An electron emission device comprising an electron emission electrode (2) with at least one pointed end and a counter electrode (3) positioned opposite to said pointed end, both formed by fine working of a substantially coplanar conductor layer (7) laminated on an insulating substrate (1), wherein at least said pointed end is composed of a material of high melting point and low work function.

2. An electron emission device according to claim 1, comprising a recess (8) on said insulating substrate (1) at least in an area between said pointed end of said electron emission electrode (2) and said counter electrode (3).

3. An electron emission device according to claim 1, wherein an attracting electrode (16; 3A, 3B) is formed above said pointed end.

4. An electron emission device according to claim 1, wherein a matrix structure is formed by wirings (18_1 - 18_5) each having plural pointed ends and by wirings (19_1 - 19_5) having counter electrodes respectively corresponding to said pointed ends.

5. An electron emission device according to claim 3, wherein said attracting electrode (16; 3A, 3B) is positioned opposite to said pointed end and is having an electrode emission aperture, wherein said attracting electrode (16; 3A, 3B) is formed on said insulating substrate (1) in substantially parallel manner to the surface of said insulating substrate (1).

6. An electron emission device according to claim 5, wherein said attracting electrode is composed of electrode members (3A, 3B) constituting a lens for converging the emitted electrons.

7. An electron emission device according to claim 6, comprising deflecting electrodes (30, 31) and/or lens electrodes (3C, 3D, 32 - 37) behind said attracting electrode (3A, 3B).

8. An electron emission device according to claim 6 or 7, comprising a recess (8) on said insulating substrate (1) corresponding to a passing area of the electrons emitted by said pointed end of said electron emission electrode (2) and/or to an area of an electric field applied to said electrons.

Pat ntansprüche

1. Elektronenemissionsvorrichtung, die eine Elektronenemissionselektrode (2) mit mindestens einem spitzigen Ende und eine dem spitzigen Ende gegenübergesetzt angeordnete Gegenelektrode (3) enthält, welche beide durch Feinbearbeitung einer auf ein isolierendes Substrat (1) laminierten, im wesentlichen koplanaren Leiterschicht (7) ausgebildet sind, wobei zumindest das spitzige Ende aus einem Material mit einem hohen Schmelzpunkt und einer geringen Austrittsarbeit gebildet ist.

2. Elektronenemissionsvorrichtung nach Anspruch 1, die an dem isolierenden Substrat (1) eine Ausnehmung (8) zumindest in einem Bereich zwischen dem spitzigen Ende der Elektronenemissionselektrode (2) und der Gegenelektrode (3) aufweist.

3. Elektronenemissionsvorrichtung nach Anspruch 1, in der über dem spitzigen Ende eine Anzugselektrode (16; 3A, 3B) ausgebildet ist.

4. Elektronenemissionsvorrichtung nach Anspruch 1, in der durch Leiterbahnen (18_1 bis 18_5), die jeweils eine Vielzahl von spitzigen Enden haben, und durch Leiterbahnen (19_1 bis 19_5), die den spitzigen Enden jeweils entsprechende Gegenelektroden haben, eine Matrix gebildet ist.

5. Elektronenemissionsvorrichtung nach Anspruch 3, in der die Anzugselektrode (16; 3A, 3B) dem spitzigen Ende gegenübergesetzt angeordnet ist und eine Elektronenaustrittsöffnung hat, wobei die Anzugselektrode (16; 3A, 3B) auf dem isolierenden Substrat (1) im wesentlichen parallel zu der Oberfläche des isolierenden Substrats (1) ausgebildet ist.

6. Elektronenemissionsvorrichtung nach Anspruch 5, in der die Anzugselektrode aus Elektrodenteilen (3A, 3B) zusammengesetzt ist, die eine Linse für das Zusammenführen der emittierten Elektronen bilden.

7. Elektronenemissionsvorrichtung nach Anspruch 6, die hinter der Anzugselektrode (3A, 3B) Ablenkelektroden (30, 31) und/oder Linsenelektroden (3C, 3D; 32 bis 37) aufweist.

8. Elektronenemissionsvorrichtung nach Anspruch 6 oder 7, die an dem isolierenden Substrat (1) eine Ausnehmung (8) aufweist, die einem Durchlaßbereich für die von dem spitzigen Ende der Elektronenemissionselektrode (2) abgestrahlten Elektronen und/oder einem Bereich eines an diese Elektronen angelegten elektrischen Feldes entspricht.

Revendications

1. Dispositif d'émission d'électrons comportant une électrode (2) d'émission d'électrons avec au moins une extrémité pointue et une contre-électrode (3) placée en opposition à ladite extrémité pointue, les deux étant formées en travaillant finement une couche conductrice sensiblement coplanaire (7) appliquée par stratification sur un substrat isolant (1), dans lequel au moins ladite extrémité pointue est composée d'une matière à haut point de fusion et faible travail d'extraction.

2. Dispositif d'émission d'électrons selon la revendication 1, comportant un évidement (8) sur ledit substrat isolant (1) au moins dans une zone entre ladite extrémité pointue de ladite électrode (2) d'émission d'électrons et ladite contre-électrode (3).

3. Dispositif d'émission d'électrons selon la revendication 1, dans lequel une électrode d'attraction (16 ; 3A, 3B) est formée au-dessus de ladite extrémité pointue.

4. Dispositif d'émission d'électrons selon la revendication 1, dans lequel une structure matricielle est formée par des fils (18_1 - 18_5) ayant chacun plusieurs extrémités pointues et par des fils (19_1 - 19_5) ayant des contre-électrodes correspondant, respectivement, auxdites extrémités pointues.

5. Dispositif d'émission d'électrons selon la revendication 3, dans lequel ladite électrode d'attraction (16 ; 3A, 3B) est placée en opposition à ladite extrémité pointue et présente une ouverture d'émission, ladite électrode d'attraction (16 ; 3A, 3B) étant formée sur ledit substrat isolant (1) d'une manière sensiblement parallèle à la surface dudit substrat isolant (1).

6. Dispositif d'émission d'électrons selon la revendication 5, dans lequel ladite électrode d'attraction est composée d'éléments (3A, 3B) d'électrode constituant une lentille destinée à faire converger les électrons émis.

7. Dispositif d'émission d'électrons selon la revendication 6, comportant des électrodes déflectrices (30, 31) et/ou des électrodes (3C, 3D, 32 - 37) de lentille en arrière de ladite électrode d'attraction (3A, 3B).

8. Dispositif d'émission d'électrons selon la revendication 6 ou 7, comprenant un évidement (8) sur ledit substrat isolant (1) correspondant à une zone passante des électrons émis par ladite extrémité pointue de ladite électrode (2) d'émission d'électrons et/ou à une zone d'un champ électrique appliqué auxdits électrons.

FIG.1

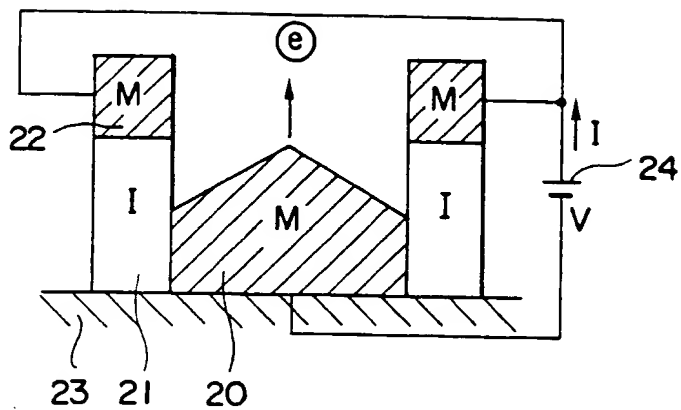

FIG.2

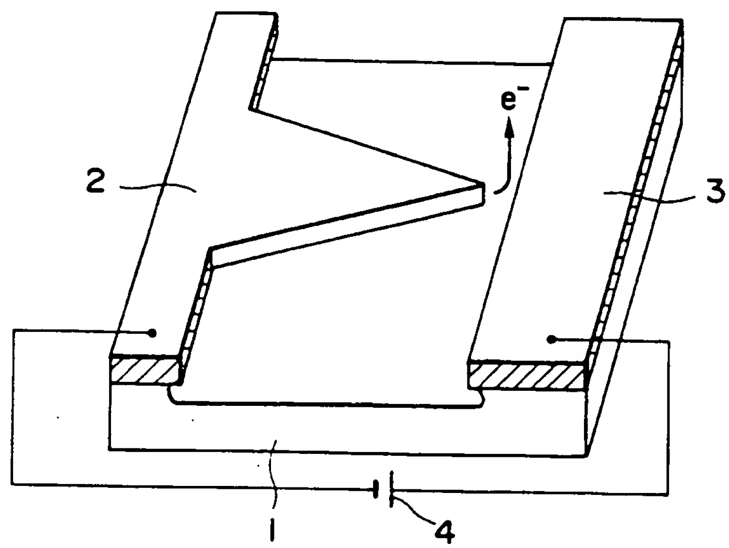

FIG.3(A)

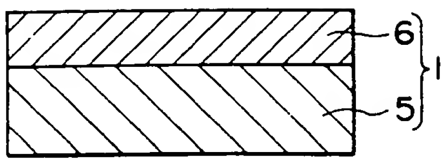

FIG.3(B)

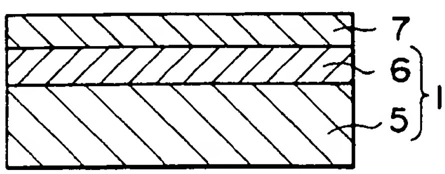

FIG.3(C)

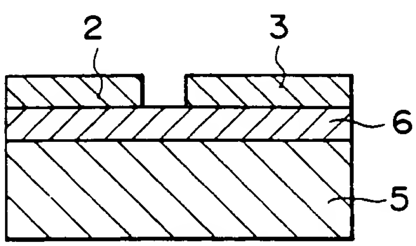

FIG.3(D)

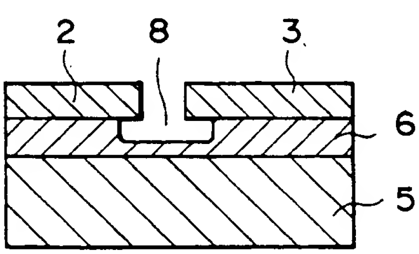

FIG.4

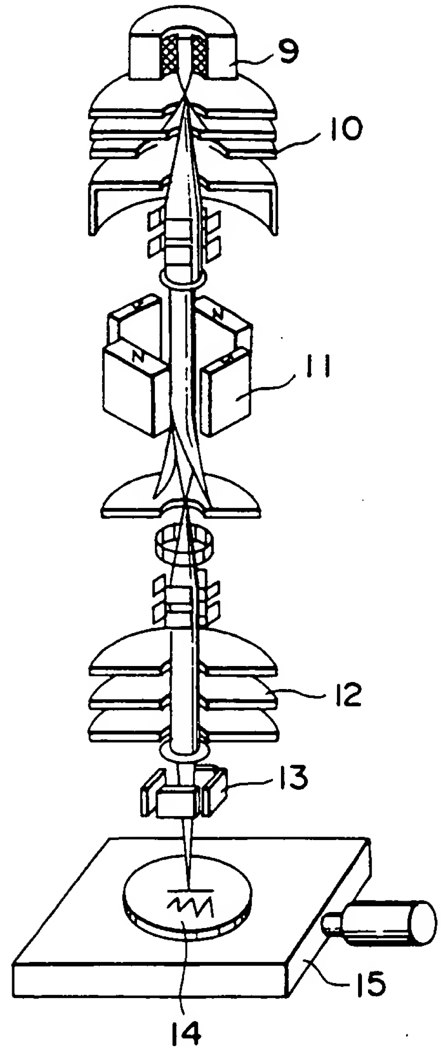

FIG.5

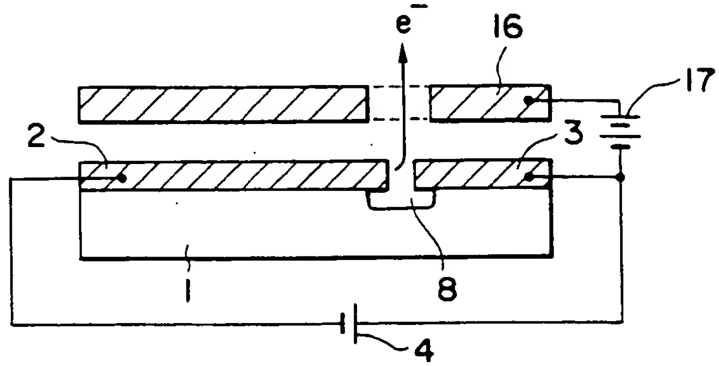

FIG.6

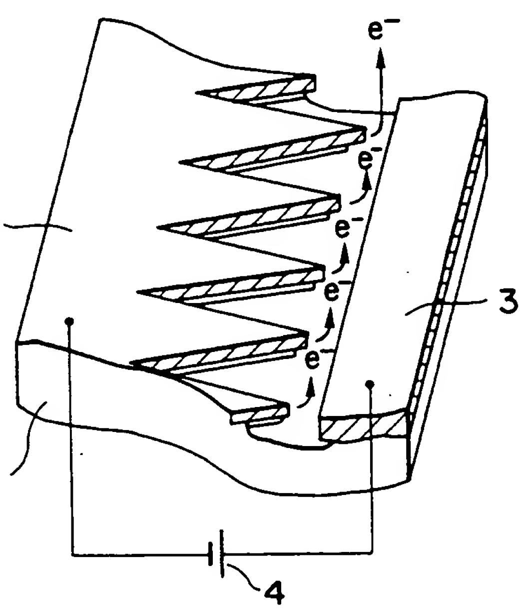

FIG.7

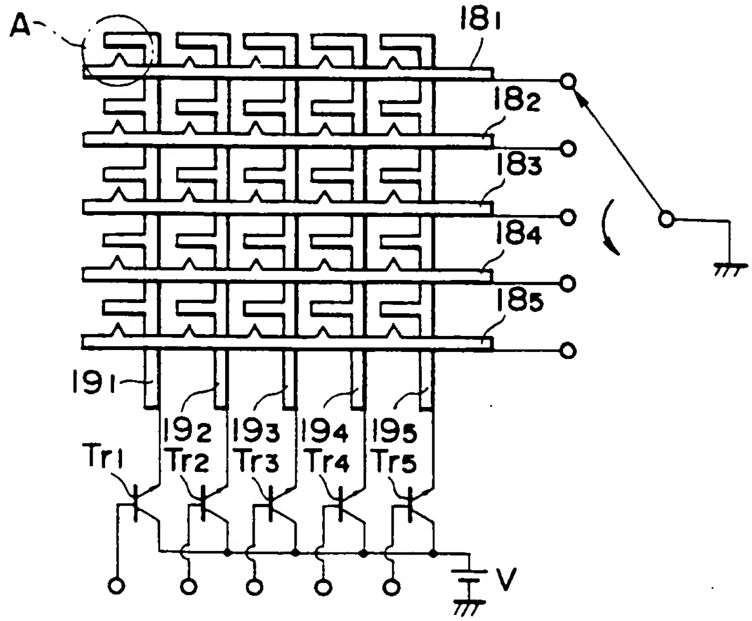
A
18_1
18_2
18_3
18_4
18_5
19_1
19_2
19_3
19_4
19_5
Tr1
Tr2
Tr3
Tr4
Tr5
V

FIG.8

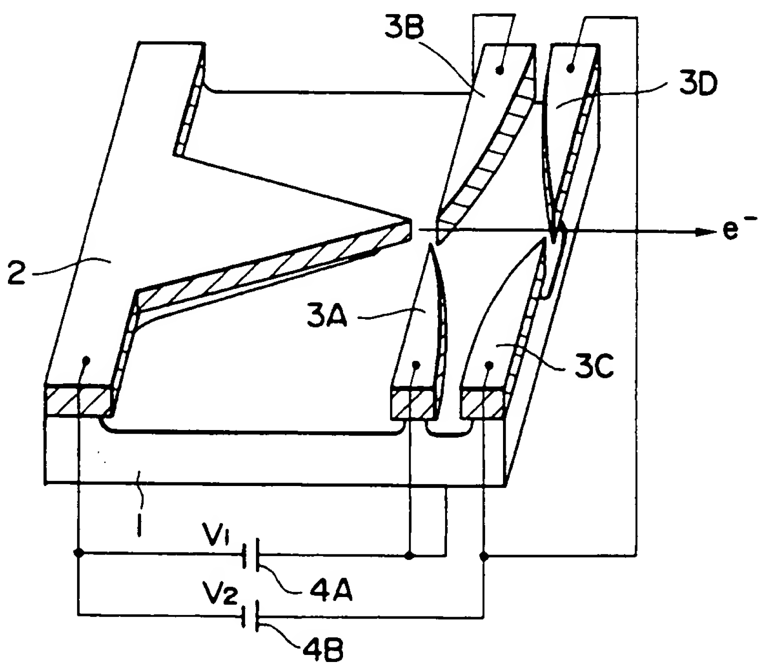
3B
3D
e⁻
2
3A
3C
1
V_1
4A
V_2
4B

FIG.9(A)

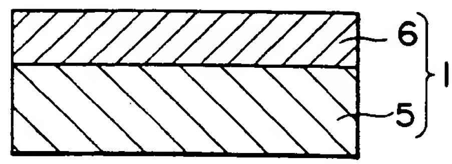

FIG.9(B)

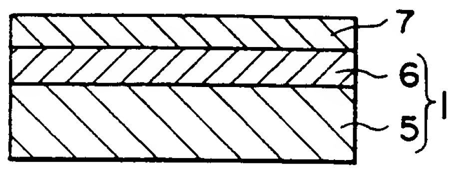

FIG.9(C)

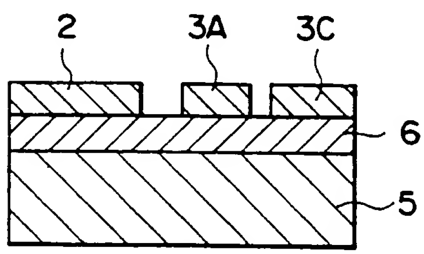

FIG.9(D)

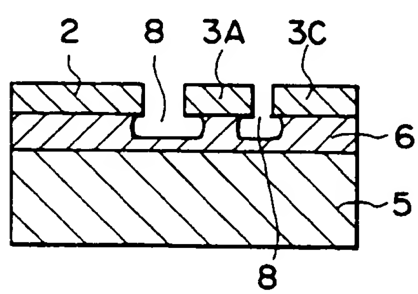

FIG.10

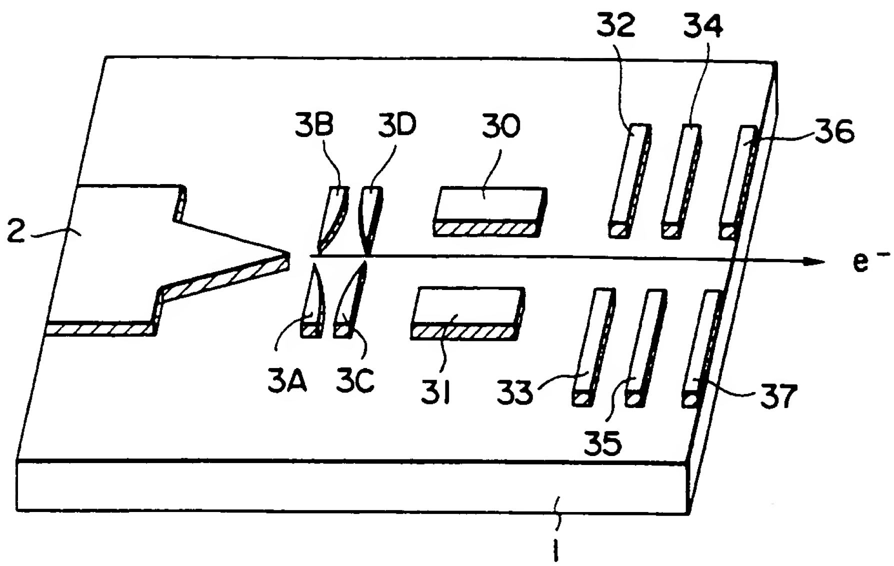

FIG.11